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# Three-dimensional Motion Analysis of Sacroiliac Joint Mobility: A Reliability Study

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**Abstract**

**Background:** Sacroiliac joint (SIJ) movement has been investigated in many studies using a motion analysis system; however, the reliability of this method has not been well defined yet.

**Objectives:** This study aimed to investigate the reliability of measuring the three-dimensional (3D) movement of the SIJ through the motion analysis system.

**Methods:** A total of 10 healthy participants performed three forward flexions from a standing position twice in one session with an interval of 30 minutes. The movements were captured by the VICON motion analysis system, and the motion of the sacrum relative to each innominate was estimated in three plans of movement. The test-retest reliability was calculated with the average of three trials using the intraclass correlation coefficient (ICC) with a 95% confidence interval (CI).

**Results:** The measurements demonstrated good to excellent reliability (ICC: from 0.61 to 0.97) that was achieved for the SIJ motion variables.

**Conclusion:** The outcomes of this study showed that the 3D motion analysis can be used for the evaluation of SIJ mobility due to its acceptable reliability.

*Keywords:* 3D motion analysis, Forward flexion test, Reliability, Sacroiliac joint

## 1. Background

The sacroiliac joint (SIJ) is one of the important joints of the body that connect the spine to the pelvis and facilitate load transfer from the upper body to the lower extremities (1, 2). Due to the anatomical configuration of the SIJ, it has a complex movement pattern and moves in combination in three planes and around three axes (2). The range of motion (ROM) is limited to about 1 to 2 mm of translation and 1 to 4 degrees of angular motion (3). The SIJ is a joint with a considerable tendency for intraarticular motion changes, and a slight decrease in the ROM is probably to occur before dysfunctions, such as low back pain, pain in the hip and inguinal region, and the pain that extends to the lower limbs (1, 4). Studies have shown that current clinical tests utilizing palpation to diagnose SIJ disorders are unreliable and invalid and may have limited clinical utility (3, 5, 6)

Among the availabl,e experimental methods, the most reliable method to evaluate SIJ mobility is fluoroscopy-guided radio stereometric analysis with contrast administration (7). However, this is an invasive and expensive method, and the interpretation of the results is difficult. On the other hand, there is no non-invasive gold standard test to assess SIJ mobility (4).

Recently, the study of human movement through three-dimensional (3D) motion analysis systems has progressed rapidly. Motion evaluation using these systems has been accepted as a suitable method for measuring SIJ motion (4, 8), but the reliability of this method needs more studies. Reliability means the repeatability of assessment processes. The repeatability of measurements in motion analysis can be affected by two factors (9). The first factor is the variability during repetitive tasks produced by individuals and the second is errors that may occur from various sources during the measurement process, such as finding the bony landmarks, sticking markers on the skin, movement of markers with skin movement, and the precision of the motion analysis system.

Although the precision of 3D motion analysis systems has improved with the advancement of technology (10-13), there are limited studies on the reliability of data obtained from this tool in the assessment of SIJ mobility (4, 13, 14) and to our knowledge, no study has examined the reliability of this instrument to assess SIJ motion in all planes.

## 2. Objectives

This study was conducted to evaluate the test-retest reliability of the 3D motion analysis system to assess SIJ mobility during the standing forward flexion test as a commonly used test in clinics for SIJ mobility assessment.

## 3. Methods

In total, 10 healthy men were included in this cross-sectional study. After receiving the explanations, the subjects signed the consent form if they agreed. Inclusion criteria were no history of surgery in the spine and lower limb, no low back pain in the past 30 days, and a normal body mass index (18 to 25[kg/m$^2$]). On the other hand, those with lower limb discrepancy of more than 1cm, subjects who had hypermobility syndrome (confirmed by the Beighton Hypermobility Index) (15), and the cases who were unable to complete the test for any reason were excluded from the study.

The motion of the SIJ was tracked by a 3D motion analysis system (VICON MX; Oxford Metrics, Oxford, England) using 10 video-based cameras at a sampling frequency of 120 Hz arranged in a laboratory to record the spatial coordination of each marker attached to the skin overlying the body landmarks. The system was calibrated on each day of data collection.

Highly reflective spherical markers (n=10) (15 mm diameter) were used to determine the anatomical landmarks of the pelvic girdle according to the study of Hungerford et al. (8) (Figure. 1). One marker was placed on the spinous process of the first lumbar spine (L1), each innominate was defined by three markers placed on the posterior superior iliac spine (PSIS), the anterior superior iliac spine (ASIS), and the lateral iliac tubercle. A three-armed triangular wand (with arms of 1 cm) with a single marker attached to the triangular base was stuck to the second sacral spinous process (S2). All markers using double-sided adhesive tape were applied directly to the skin (not on the shorts) in a standing position. The markers were placed by one individual trained examiner for all participants.

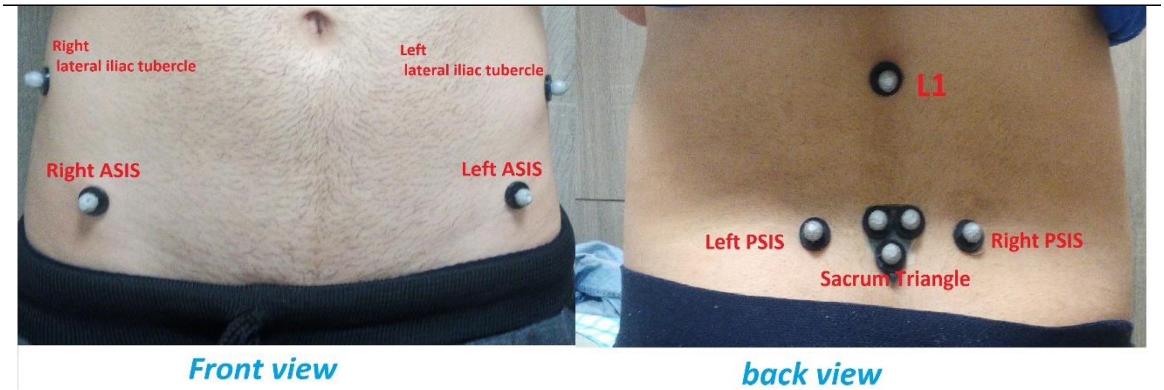


**Figure 1.** Marker set up

After preparation and familiarization, the participants stood barefoot in a standing position and performed three forward flexions to the end of the possible range and back to the resting position at their preferred speed, and the movement was recorded by the VICON system. There was a 30-minute break between tests and retests.

This study was authorized by the Research Ethics Committee of the University of Social Welfare and Rehabilitation Sciences and carried out at the gate laboratory of the Djavad Mowafaghian Research Center for intelligent neurorehabilitation technologies at Sharif University of Technology in 2020.

### 3.1. Data analysis

The 3D motion of each marker during the task was recorded by the VICON motion analysis system, and the raw data were imported into MATLAB (MATLAB and Statistics Toolbox Release 2017b, The MathWorks, Inc., Natick, Massachusetts, USA). 3D angles have been extracted by a Cardan XYZ (flexion/extension-lateral bend-axial twist) rotation sequence. The flexion/extension angles have been used in this study. The Cardan rotation sequence XYZ involves three steps. First, rotation about the laterally directed axis (X [flexion/extension]); second, rotation about the anteriorly directed axis (Y [lateral bend]); and third, rotation about the vertical axis (Z [axial twist]). After Local Coordinate System computation for each segment, the resulting orientation matrix has been used for extracting 3D angles. The angles for the XYZ sequence are designated α (alpha) for the first rotation, β (beta) for the second rotation, and ϒ (gamma) for the third rotation. The rotation matrix R and α angle for an XYZ rotation sequence are as follows (16, 17):

$$R=\begin{bmatrix} \cos\gamma\cos\beta & \cos\gamma\sin\beta\sin\alpha+\sin\gamma\cos\alpha & \sin\gamma\sin\alpha-\cos\gamma\sin\beta\cos\alpha \\ -\sin\gamma\cos\beta & \cos\alpha\cos\gamma-\sin\gamma\sin\beta\sin\alpha & \sin\gamma\sin\beta\cos\alpha+\cos\gamma\sin\alpha \\ \sin\beta & \cos\beta\sin\alpha & \cos\beta\cos\alpha \end{bmatrix}$$

$$\alpha=\tan^{-1}\left(\frac{-R_{32}}{R_{33}}\right)$$

All motion parameters were excluded at the maximum sagittal displacement of the L1 marker relative to the S2 markers during forward flexion. Outcome measures were the translation and rotation of the sacrum relative to each innominate (2 sides) in the sagittal, frontal, and transverse planes (2*2*3=12). The statistical analysis was performed by SPSS software (version 25.0 IBM Corp., New York, NY). The characteristics of the subjects were described by the mean and standard deviation (SD). The relative test-retest reliability was calculated with the average of three trials using the intraclass correlation coefficient (ICC) with a 95% confidence interval ($P<0.05$). The results were interpreted as excellent reliability: ICC ≥ 0.75, good reliability: 0.40 < ICC < 0.75, and poor reliability: ICC ≤ 0.40 (18).

## 4. Results

In total, 10 subjects (aged from 20 to 35 years) were included in this study without any sample attrition. The characteristics of the subjects are shown in Table 1. The results of the ROM and the test-retest reliability (ICC) are described in Table 2. The mean angular motion was 2.42° (ranging from 1.29 to 3.7), and the mean translation was 3.28 mm (ranging from 2.03 to 5.44). The ICC was good to excellent. The lowest amount of ICC was for sacral flexion at the right (0.61), and the highest amount was for vertical translation at the left (0.97). The average ICC was obtained at 0.84.

**Table 1.** Main characteristics of the subjects

| Parameter | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| **Age** | 20 | 35 | 26.10 | 4.43 |
| **Height** | 166 | 187 | 174.70 | 7.10 |
| **Weight** | 53 | 77 | 66.10 | 8.63 |
| **BMI** | 19.23 | 24.02 | 21.58 | 1.88 |

**Table 2.** ROM and ICC of the measured parameters

| Variables | SIJ Motion | ROM (left) | ROM (right) | ICC* Test-retest (left) | ICC* Test-retest (right) |
|---|---|---|---|---|---|
| **Angular motion (°) Mean ±SD** | Coronal axis (Sacral Flexion) | 1.44±1.14 | 1.29±1.1 | .65 | .61 |
| | Sagittal axis (Sacral Tilt) | 2.47±1.12 | -2.26±1.07 | .93 | .95 |
| | Vertical axis (Sacral Rotation) | 3.36±1.19 | -3.7±.95 | .85 | .92 |
| **Translation(mm) Mean ±SD** | Antero-Posterior | 5.44±3.34 | 5.01±3.47 | .81 | .87 |
| | Medio-Lateral | 2.57±1.96 | -2.26±1.56 | .77 | .82 |
| | Vertical | 2.42±.84 | 2.03±.56 | .97 | .95 |

Positive Flexion=anterior; Positive Tilt=toward right; Positive Rotation=toward left
Positive Antero-Posterior translation=anterior; Positive Medio-Lateral translation=right;
Positive vertical translation=superior
*$P< 0.05$

## 5. Discussion

The evaluation of SIJ mobility is very useful because it helps to diagnose the disorders of this joint. Biomechanical changes in the SIJ are difficult to detect during clinical assessment, and palpation-based tests lack sufficient reliability for this goal (3, 5, 6) The present study shows that test-retest reliability using an experienced technician is good to excellent for all of the SIJ motion variables. The 3D kinematics analysis was adopted as a method to improve the accuracy of motion assessment and as an alternative to palpation used in manual testing. The lowest reliability value was obtained for the flexion movement (0.61 and 0.65) which also had the lowest range of motion. This can be related to the calculation method because if the range of values is small, the reliability value decreases (9).

Our study results are in agreement with the findings in the literature suggesting that the use of laboratory hardware and software can increase the precision of analysis (4, 8) Webster et al.(19) demonstrated excellent reproducibility and excellent intra-rater agreement when they compared two different motion analysis systems (GAITRite® and VICON-512®). The VICON system has enough accuracy to measure displacements in millimeters (12).

Our results were in agreement with the findings by Rebello et al.(4) which found excellent intra-observer reliability (ICCs from 0.91 to 0.94) in the 3D analysis of SIJ mobility. However, their outcome measure was the magnitude of the displacement between PSIS and contralateral trochanter as an indirect estimate of SIJ motion, whereas the present study analyzed sacroiliac motion directly in all three planes.

Clinical tests provide only qualitative data, but one of the biggest advantages of using a motion tracking system is the ability to record reliable quantitative data about ROM(4, 14). Beth Moody et al.(20) showed that there was hypomobility at SIJ in the subjects with positive Gillet test, compared to the subjects with negative Gillet test. They compared the magnitude of SIJ motion in the two groups using a 3D motion analysis system; therefore, this study emphasizes the use of this system to determine the accuracy of manual assessment results.

Jacob and Kissling (21) showed a smaller amount of translation (between 0.4mm and 0.71mm) and rotation (between 0.59° and 1.1°) for the SIJ in three axes, which is different from the results of our study where the average displacement value was 3mm, and an average angular motion was 2°. They had calculated the sacroiliac movement by Cam k-wires, which is an invasive method and tracks the bone movement directly, but in the present study, movement tracking was done through skin markers, in which skin movement on the bone -as a soft tissue artifact- may increase the measured values.

However, this error can be minimized by selecting subcutaneous bony landmarks with little overlying tissue. This justification is supported by the study of Hungerford et al.(8), where they measured SIJ mobility with a motion analysis system through skin markers, and the mean value of displacement was 4 mm, and the mean angular motion was 6 degrees.

Regarding the limitations of the study, the authors assessed intra-session and intra-rater reliability. Therefore, when the assessment is done by two assessors, and there is a longer interval between the test and retest, the results may be different. Moreover, the sample size of the present study was small; accordingly, caution should be taken in interpreting its results.

## 6. Conclusion

Based on the results of this study, 3D motion analysis has the acceptable possibility and test-retest reliability for the evaluation of SIJ mobility. Future studies with a larger sample size and evaluation of inter-session and inter-rater reliability on subjects with SIJ dysfunction are needed to better judge this method.

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## Footnotes

**Conflicts of Interest:** None.
**Authors' Contributions:** All authors made substantial contributions to the conception, design, acquisition, analysis, and interpretation of data.
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**Informed Consent:** Written informed consent was obtained from all participants.

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